海外情報連絡会、材料部会、核燃料部会 合同セッション

フランスのエネルギー政策とジュールホロビッツ材料照射試験炉

(2) ジュールホロビッツ材料照射試験炉と照射実験設備、照射計画について

(2) Introduction of Jules Horowitz Reactor: construction schedule, reactor capabilities, irradiation facilities and irradiation plans

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1. Introduction

The Jules Horowitz Material Testing Reactor (JHR) is currently under construction on the CEA Cadarache site. JHR will be operated as an international user's facility for materials and fuel irradiations for the nuclear industry or research institutes but it is also dedicated to the radioisotopes production for medical applications.

The construction is made within an international framework. Consortium members are presently: CEA, EdF, Framatome, TechnicAtome, Areva-SA (France); EC and JRC (European Commission); CIEMAT (Spain); VTT (Finland); UJV (Czech Republic); Studsvik (Sweden); NNL (UK); DAE (India); IAEC (Israel).

The design of this facility allows a large flexibility in order to comply with a broad range of experimental needs, regarding the type of samples (fuels or materials), neutron flux and spectrum, type of coolants and thermal hydraulics conditions (LWR, Gen IV,…), in accordance with the scientific objectives of the programs. The design of the reactor and the facility allows accounting for the current irradiation needs from the present reactor technologies as well as future needs from advanced or innovative technologies for the next 60 years.

2. JHR General description

This facility is a 100 MWth pool type reactor with a compact core (60cm fissile length, 70 cm diameter) cooled by a slightly pressurized primary circuit (about 1MPa, in-core water velocity: 15m/s). The core tank is located in a reactor pool of 7 m diameter, 12 m height.

The nuclear facility comprises a reactor building with all systems dedicated to the reactor and experimental devices; and an auxiliary building dedicated to tasks in support for reactor and experimental devices operation (hot cells, storage pools, laboratories).

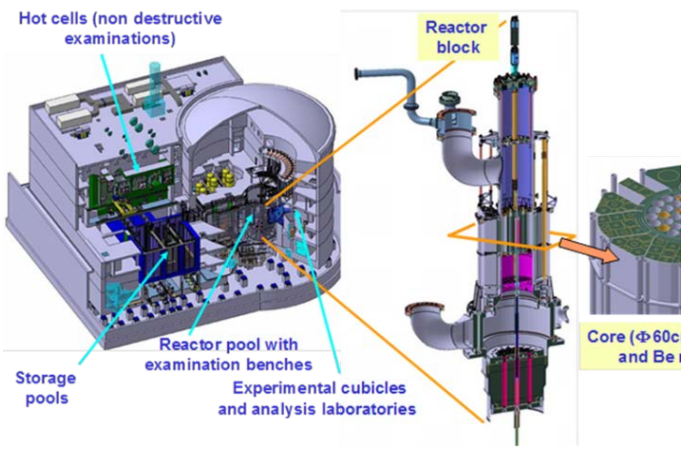

Figure 1. View of the JHR facility.

The reactor building (see figure 1) is designed to provide the largest experimental capacity possible with the largest flexibility. One-half of this building is dedicated to the implementation of devices linked to the in-pile irradiations (for example, water loops). This corresponds to 700 m2 over 3 floors for implementation of experimental cubicles and 490 m2 over 3 floors for instrumentation and control systems.

The design of the core provides irradiation cavities:

- Located in the core (7 of small diameter – 30mm; 3 of large diameter – 80mm) which are characterized by a high fast neutron flux (up to $5{,}5.10^{14}$ n.cm^{-2}.s^{-1} above 1MeV) and therefore by a high ageing rate (up to 16 dpa/year),
- Located in the Beryllium reflector zone surrounding the core, (about 20, most of them of 100mm diameter), with a high thermal neutron flux (up to 3,5. 10^{14} n.cm^{-2}.s^{-1}). Note that material experiments requiring a low ageing rate (such as the pressure vessel steel) will be installed in the reflector because of the low fast neutron flux which allows an ageing rate of about 0,1dpa/y,
- Four to six water channels (depending on the core configuration) through the reflector are equipped with displacement devices to control accurately the distance to the core and therefore the irradiation flux (for an accurate stable power, for power ramps, or for power cycling...). The velocity (forward: maxi 5 mm/s) makes possible to reach 700 W.cm^{-1}.min^{-1} even with very high burn-up fuels. The range of displacement allows getting three orders of magnitude for the neutron flux. Withdrawal velocity of 50mm/s allows going back fast in a safe position for safety purpose.

The facility is designed to operate 20 experiments simultaneously. CEA targets to operate the reactor at least 10 cycles of about 1 month per year.

The JHR experimental capacity will also include several non-destructive examination (NDE) benches: A coupled gamma scanning and X-ray tomography bench located in the reactor pool, a similar bench located in the storage pool of the Nuclear Auxiliary Building. A neutron imaging system bench located in the reactor pool.

3 STATUS (civil work and reactor components)

Site work started in 2007 when the JHR consortium was set up. The concrete of the first basement has been poured in 2009. The following figure gives the main milestones. The civil work of the reactor building is presently almost completed.

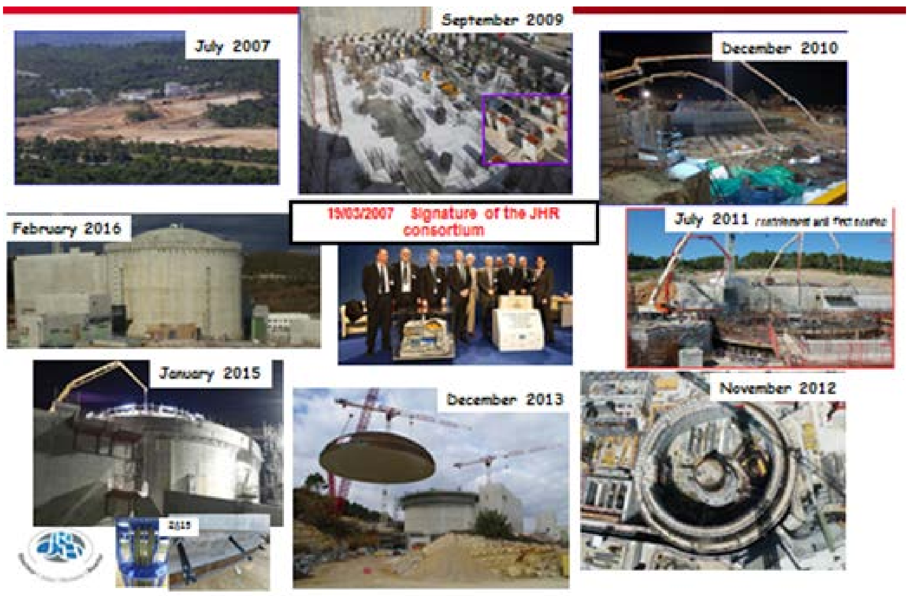

Figure 2: main milestones of the civil work

Most of the main components of the reactor are manufactured, some of them are under testing phase, and the installation in the facility will start in 2019. First criticality is expected by the middle of the next decade.

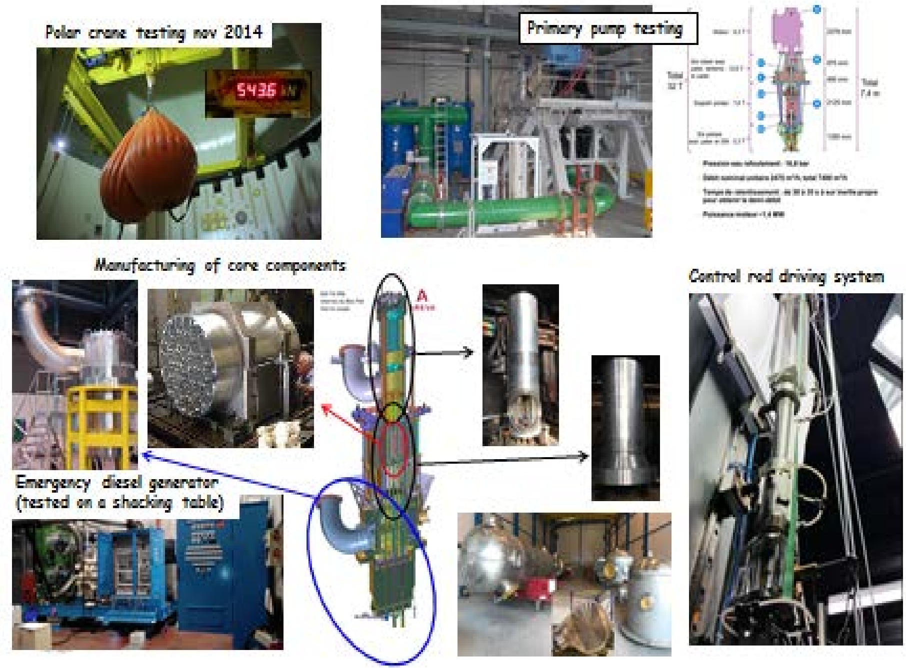

Figure 3: some reactor components

4 Description of the fuel and material irradiation devices

Fuel test devices are presently under development, a specific effort is done for the test devices (under manufacturing process) dedicated to light water reactors (PWR including VVER & BWR,):

- Madison dedicated to the fuel investigations under nominal conditions, (evolution of the fuel microstructure, clad corrosion, fission gas releases …),
- Adeline dedicated to off-normal situations, the reference situations for the design of the loop are the power ramps,
- Lorelei dedicated to accidental situations, the reference situation for the design of the loop is the LOCA – large break.

Moreover, conceptual design of test devices dedicated to non-water NPP (GEN IV) are in progress.

Similarly, to the fuel, CEA made the decision to develop first new irradiation devices in support of LWR type reactors, taking benefit of the know-how of the previous reactors (particularly OSIRIS).

Mica and Calipso dedicated to the material studies under high ageing rate with representative thermal conditions, neutron fluxes and possibly under stresses.

- Occitane dedicated to pressure vessel steel testing (low ageing rate),
- Cloe dedicated to IASCC studies (Irradiation Assisted Stress Corrosion Cracking).

Right now, CEA anticipates the fourth generation research program; a first analysis of the SFR or GFR irradiation needs for materials and fuels has been performed. Accordingly, some feasibility studies have begun in order to prepare future irradiations in JHR.

After analysing the needs linked to the fusion technology, three conceptual designs (FUSERO test devices) are under preparation:

- Thermo-Mechanical Fatigue testing: study of components submitted to both mechanical strain and thermal strain (from the breeding blanket to divertor tiles).

- Ceramic testing (for diagnostic windows); samples bi-axially loaded, analysis of optical properties and sub-critical crack growth.
- Cryogenic testing for the study of electrical and structural properties of superconducting magnet materials.

Generally speaking, CEA is maintaining significant R&D programs to improve the performances of the experiments (especially by putting innovation on instrumentation, with a specific effort for on-line measurements and on NDE technics). With the help of improved modelling, efforts of development are in progress on test devices designed to match the requirements and to provide around experimental samples accurate, mastered and reproducible physical and chemical conditions.

5 Start-up test devices

The objectives of the start-up test devices are the verification of the performances of the facility, the verification of the safety parameters but also the accurate determination of the irradiation parameters in the experimental cavities. This last point is specifically a challenge because JHR has to be as accurate as the present MTRs, which started to operate at least 40 years ago…

The preparation of these test devices led to optimize the strategy for the start-up tests (timing of the tests, accuracy, power level, reactor configuration…) and to analyse the needs in terms of instrumentation:

- Neutron flux and gamma heating mapping, neutron spectra,
- Fissile power, reactivity measurement, in core void effect evaluation,
- Thermal-Hydraulics (flowrate in experimental cavities, in core, in reflector; core under free convection...),
- Devices dedicated to the thermal mapping of the reactor structural materials.

6 First orientations of the experimental programs

A specific organization has been set up within JHR consortium framework in order to:

- Identify the open issues in the field of nuclear fuel and material development and qualification,
- Define criteria to elaborate ‘ranking grids” about fuels/materials types, reactor systems,
- Define experimental objectives and initiate the future R&D programs.

Generally speaking, accent is given on the mastering and follow-up of the irradiation conditions in terms of local neutron flux and spectrum, temperature homogeneity and thermal gradients, with the possibility to un/re/load irradiated materials in the JHR experimental devices. The priority is given on Gen II-III power systems. This analysis led to a “Position Paper” and a first proposal for a JHR International Joint program. The objective of this first international joint program is to gather the scientific community on JHR experimental objectives before the reactor start-up.: a first set of experiments will be performed in existing facilities and the program will be carried on in JHR. The experimental proposal deals with fuel and material objectives;

- Fuel behaviour (improvement of the understanding of the phenomena involved in power transients and having an impact on the clad loading: quantification of the fission gas release effect and impact on pellet-clad interaction during a power transient consisting in successive small power steps).
- And material behaviour (effect of neutron spectrum on Stainless Steel behaviour): dose-damage relationship quantified by tensile testing and microstructure characterizations.